Organic compounds in biomass smoke from residential wood combustion: Emissions characterization at a continental scale

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[1] Wood smoke in the atmosphere often accounts for 20–30% of the ambient fine-particle concentrations. In communities where wood is burned for home heating, wood smoke can at times contribute the majority of the atmospheric fine-particle burden. Chemical mass balance receptor models that use organic compounds as tracers can be used to determine the contributions of different emission sources, including wood smoke, to atmospheric fine-particle samples. In order for organic chemical tracer techniques to be applied to communities across the United States, differences in wood smoke composition that arise from differences in the type of wood burned in various regions must be understood. A continental-scale accounting of particulate organic compound emissions from residential wood combustion has been constructed which helps to quantify the regional differences in wood smoke composition that exist between different parts of the United States. Data from a series of source tests conducted on 22 North American wood species have been used to assemble a national inventory of emissions for more than 250 individual organic compounds that are released from wood combustion in fireplaces and wood stoves in the United States. The emission rates of important wood smoke markers, such as levoglucosan, certain substituted syringols and guaiacols, and phytosterols vary greatly with wood type and combustor type. These differences at the level of individual wood type and combustion conditions translate into regional differences in the aggregate composition of ambient wood smoke. By weighting the source test results in proportion to the availability of firewood from specific tree species and the quantities of wood burned in each locale, it is possible to investigate systematic differences that exist between wood smokes from different regions of North America. The relative abundance of 10 major wood smoke components averaged over the emissions inventory in different regions of the United States is computed and then used to illustrate the extent to which wood smoke composition differs from region to region in North America. *INDEX TERMS:* 0305 Atmospheric Composition and Structure: Aerosols and particles (0345, 4801); 0345 Atmospheric Composition and Structure: Pollution—urban and regional (0305); 9350 Information Related to Geographic Region: North America; *KEYWORDS:* biomass, smoke, particle, organics, GC/MS, tracers

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1. Introduction

[2] Assessing the contribution of residential wood combustion to ambient fine-particle concentrations presents a difficult challenge for environmental scientists and policymakers for a variety of reasons. Residential wood-burning activity can vary significantly from region to region and from season to season. The amount of wood being burned can also vary on a daily or hourly basis depending on outdoor temperatures and the day of the week. The types of woods being burned also depend on region and can produce different fine-particle emission rates [*Fine et al.*, 2001, 2002; *McDonald et al.*, 2000; *Schauer et al.*, 2001; P. M. Fine et al., Chemical characterization of fine particle emis-

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sions from the fireplace combustion of woods grown in the western United States; P. M. Fine et al., Chemical characterization of the fine particle emissions from the wood stove combustion of prevalent United States wood species; P. M. Fine et al., Chemical characterization of the fine particle emissions from the fireplace combustion of woods grown in the midwestern United States, submitted to *Environmental Science and Technology*, 2001; hereinafter referred to as submitted manuscript, 2001a, 2001b, and 2001c, respectively]. Different wood combustion appliances, including wood stoves, fireplaces, and any corresponding emissions control equipment, can lead to very different emission characteristics even when the same woods are burned [*McCrillis and Burnet*, 1990; *McCrillis et al.*, 1992; *McDonald et al.*, 2000]. Other factors such as fuel moisture content, burn rate, log size, and log configuration also can significantly affect emission rates [*Burnet et al.*, 1986; *McCrillis and Burnet*, 1990; *McCrillis et al.*, 1992; *Stern et al.*, 1992]. Currently, the best estimates of the amount of fine-particulate matter emitted to the atmosphere from residential wood combustion are based on emissions inventory approaches. According to the U.S. Environmental Protection Agency (USEPA) 34% of the total nonfugitive dust $PM_{2.5}$ emissions in the United States during calendar year 1995 came from biomass combustion sources, with 36% of that figure coming from residential wood combustion [*USEPA*, 2000]. However, these annual emissions estimates do not help in determining the contribution of residential wood combustion fine-particle emissions to specific pollution events, which instead tend to reflect day-to-day variations in home-heating demand as well as meteorological conditions.

[3] Instead of estimating the relative importance of wood smoke on the basis of emissions inventory calculations, chemical mass balance receptor models can be used to determine the fraction of ambient fine particle mass attributable to a particular source [*Schauer and Cass*, 2000; *Schauer et al.*, 1996; *Watson*, 1984]. By comparing detailed fine-particle organic chemical composition data from emissions source tests with the corresponding chemical composition of ambient fine-particle samples, a nearly complete source apportionment of the atmospheric fine-particle burden can be achieved. These methods require the use of unique particle phase chemical markers or source signatures to effectively trace emissions from a particular source. For biomass combustion sources such as residential wood combustion, nonsoil potassium has been proposed as a wood smoke marker [*Echalar et al.*, 1995]. However, particulate potassium has other emission sources, such as meat cooking [*Schauer et al.*, 1999] and refuse incineration [*Olmez et al.*, 1988; *Sheffield et al.*, 1994], which complicate its use as a wood smoke tracer. Isotopically "modern" carbon has also been used as a biomass combustion marker [*Currie et al.*, 1994; *Sheffield et al.*, 1994], but this too has other sources such as food cooking, cigarette smoking, and the abrasion products from leaf surfaces [*Hildemann et al.*, 1994]. A better source of possible wood smoke tracers can be found in the over 250 individual organic compounds previously identified in wood smoke [*Fine et al.*, 2001, 2002; *McDonald et al.*, 2000; *Schauer et al.*, 2001; *Simoneit et al.*, 1993, 2000; P. M. Fine et al., submitted manuscript, 2001a, 2001b, 2001c]. Potential marker compounds include substituted phenols, resin acids, and certain phytosteroids, all of which are relatively unique to biomass combustion.

[4] The use of organic compounds as tracers in chemical mass balance receptor models has been successfully demonstrated at specific locales in California. Over a 3-day period in Fresno, California, in 1995, over 50% of the ambient fine-particle concentration was demonstrated to be due to wood combustion using these methods [*Schauer and Cass*, 2000]. Another chemical mass balance calculation using organic compounds determined that for a 1982 annual average in southern California, up to 10% of the ambient fine-particle mass consisted of wood smoke [*Schauer et al.*, 1996]. However, if these methods are to be applied at a national scale, source chemical composition profiles which reflect regional differences in wood types and appliance use may be necessary. At the present time the extent of region-to-region differences in wood smoke composition in North America is completely unknown.

[5] It has already been shown that different wood species and different combustion appliances can produce different mass emission rates and organic compound source signatures [*Fine et al.*, 2001, 2002; *McDonald et al.*, 2000; P. M. Fine et al., submitted manuscript, 2001a, 2001b, 2001c]. Hardwood combustion emits significantly more substituted syringol compounds than softwood combustion, and resin acids are emitted only from the burning of softwoods. The emission rates of certain phytosterols, such as β-sitosterol, can vary greatly with wood species [*Fine et al.*, 2001, 2002; P. M. Fine et al., submitted manuscript, 2001a, 2001b, 2001c]. Other organic species, such as betulin, friedelin, juvabione, and yangambin, may be unique to a particular wood species or class [*Fine et al.*, 2001, 2002; P. M. Fine et al., submitted manuscript, 2001a, 2001b, 2001c]. Furthermore, although wood stoves and fireplaces emit similar compounds when burning the same wood type, the relative amounts of these compounds can differ as combustion parameters are changed. A single residential wood combustion organic compound source profile might not be applicable for use across North America because wood species availability and appliance ownership vary regionally.

[6] To quantify the extent of regional variations in wood smoke organic chemical composition, an extensive series of source tests was conducted while burning the most available wood species in the United States [*Fine et al.*, 2001, 2002; P. M. Fine et al., submitted manuscript, 2001a, 2001b, 2001c]. The methods for selecting the wood species, conducting the source tests, and analyzing the particulate emissions have been reported previously [*Fine et al.*, 2001]. Twenty-two wood species were burned in a conventional masonry home fireplace, and five of these species were also tested in a wood stove operated with no emission control technology. The resulting source organic chemical composition profiles for individual wood species burned in both fireplaces and wood stoves are also given in the previous publications cited above. The goal of the present paper is to demonstrate how these previous results can be used in conjunction with data on wood-burning activity, appliance ownership, and wood species availability to construct regional average residential wood smoke source profiles for use in chemical mass balance calculations. The regional variability of wood smoke organic chemical composition will be illustrated by particular reference to differ-

ences in emissions rates of 10 of the most important organic compounds in wood smoke.

2. Methods

[7] The method for calculating composite regional source profiles for residential wood combustion is somewhat analogous to the process of creating weighted overall emissions profiles for motor vehicles based on the mix of vehicle types in the fleet and selected source emissions data [*Schauer et al.*, 1996]. In the case of residential wood combustion, data on the geographical distributions of appliance types and total wood use are combined with source testing results and data on the availability of individual wood species to calculate an overall emission profile for all residential wood combustion in a particular region.

[8] The year 1995 was selected as the base year for this study. That year was chosen to correspond with a set of ambient samples collected for future comparison against the source test data using chemical mass balance receptor modeling techniques. First, the amount of wood burned in each of the 48 contiguous Unites States and the District of Columbia was taken from U.S. Department of Energy (USDOE) data on energy sources for residential home heating [*USDOE*, 1997]. Values given in British thermal units (Btu) were converted to mass of wood burned using their stated conversion factors of 20 million Btu (20.1 GJ) per cord and 1.25 short tons (1134 kg) per cord of wood. Additional data from the USDOE on the amount of wood burned as the main space-heating fuel in each U.S. census division in 1993 were used to apportion wood consumption between primary and secondary home-heating purposes [*USDOE*, 1995]. The difference between total wood consumption and primary heating wood consumption is defined as secondary wood consumption within each U.S. census division. The resulting primary versus secondary fractions in each U.S. census division were applied to each state's total wood consumption estimates.

[9] Next, both primary and secondary wood consumption in each state was divided into wood burned in wood stoves and wood burned in fireplaces. This was accomplished using USDOE data on heating equipment use by households that use wood as a primary heating fuel and households using wood as a secondary heat source [*USDOE*, 1993, 1999]. All wood-burning appliances other than heating stoves were assumed to be fireplaces, although this figure may include a small number of wood-burning furnaces. In order to best approximate the target year of 1995 and to lessen statistical errors associated with small sampling numbers in the surveys, 1993 and 1997 data from USDOE were averaged. The fraction of wood use by wood stoves and fireplaces within each U.S. census region and for both primary and secondary wood consumption were applied to the corresponding state totals for primary and secondary wood burning. The total amount of wood burned in each state, apportioned between fireplaces and wood stoves, was calculated as the sum of primary and secondary consumption by each of the two wood-burning appliance types.

[10] Existing tree stand inventory data from the U.S. Forest Service (USFS) show the wood species that are most abundant in each state [*USFS*, 1998]. Making the assumption that people burn the wood species which grow in their vicinity [*Smith and Weatherspoon*, 1990], the wood burned in each state is apportioned between tree species in direct proportion to the standing tree species distribution within that state. Tree species data from Oregon and the District of Columbia were not available, so the data for Washington State and Maryland were applied, respectively.

[11] The wood use data described above next were translated into emissions estimates for wood combustion in fireplaces and wood stoves in each state. Emission rates per kilogram wood burned for components such as fine particle mass, organic carbon, and over 200 individual organic compounds have been previously determined for the fireplace and wood stove combustion of the most available wood species in the United States [*Fine et al.*, 2001, 2002; P. M. Fine et al., submitted manuscript, 2001a, 2001b, 2001c]. The fine-particle emissions from the fireplace combustion of 22 wood species, chosen for their high level of national availability on the basis of the same forestry surveys mentioned above, were examined in a set of comprehensive source tests. The top five nationally available wood species were also tested in a wood stove operated without emissions controls. A complete list of the tested wood species, along with the method for calculating their levels of availability, is provided in a previous work [*Fine et al.*, 2001]. While it is impractical to conduct source tests on every wood species burned in the United States, the wood species chosen for testing in the fireplace experiments conducted here account for approximately 60% of the wood burned nationally. For the remaining wood species for which source tests were not performed, emission factors were estimated on the basis of the results for the other woods. The composition of the emissions from all examples of oak, maple, and pine woods tested were averaged within their respective groups and then used to represent all other untested oak, maple, and pine species. For all remaining woods the overall average emission characteristics for hardwoods and softwoods were utilized. Wood stove emission factors for the one oak and one pine species tested were applied to all oak and pine species burned in wood stoves, respectively. Average wood stove emission factors derived from the two maple species tested were applied to all other maple species burned in wood stoves. All other woods burned in wood stoves were represented using the average hardwood or softwood emission factors for wood stove combustion as appropriate. Overall emissions rates for each chemical species of interest were calculated for each state by summing the emissions of that chemical species across all of the wood types burned in the state.

[12] Several qualities are desired when seeking to define potential particle phase organic tracers for specific emissions sources. A high molecular weight corresponding to a low vapor pressure is important to ensure that the compound partitions primarily into the particle phase. High emission rates increase the likelihood that the compound can be detected in ambient samples. Compounds that are unique to a particular source are especially sought after as such compounds facilitate the chemical mass balance calculations. Finally, useful tracer compounds should react slowly enough in the atmosphere to survive transport between source and receptor site. Using these criteria, 10 organic compounds that act as potential markers for wood

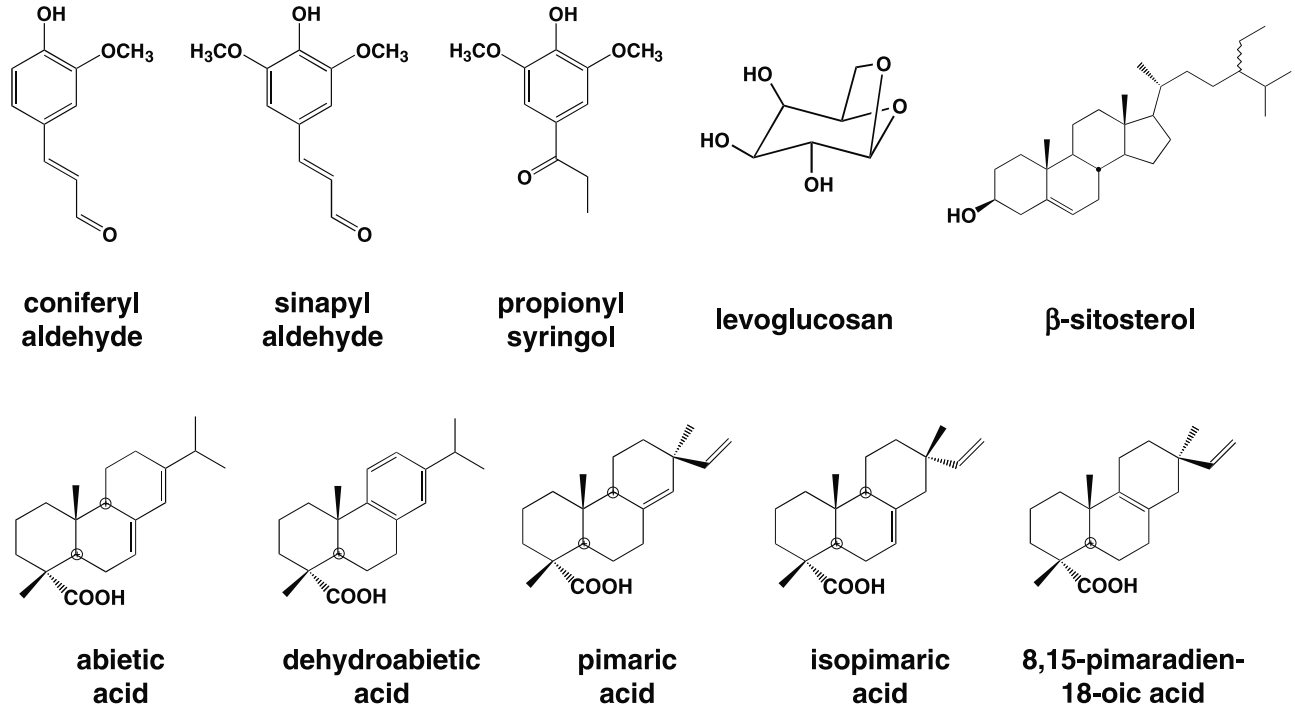

Figure 1. Names and structures of the organic compounds selected as wood smoke tracers for this study.

smoke from among the over 200 compounds inventoried were selected to demonstrate regional variations in residential wood combustion source profiles. The names and structures of these compounds are shown in Figure 1. A discussion of their usefulness as wood smoke tracers appears in section 3.

[13] Using the appropriate emission factors, the total 1995 residential wood combustion emissions of fine-particle mass, organic carbon, and the 10 selected tracer compounds were calculated for each of the 48 contiguous United States. The state totals were then combined into regions corresponding to the 10 U.S. Environmental Protection Agency regions, excluding Alaska and Hawaii. Results for individual organic compounds are stated as a fraction of the total fine-particle organic carbon emitted in wood smoke in each region.

3. Results and Discussion

[14] Table 1 lists selected results of the calculations for fine-particle emissions from residential wood combustion in the continental United States in 1995, organized by EPA region. Total $PM_{2.5}$ emissions are normalized by mass of wood burned, land area, and population in order to compare the emissions characteristics from region to region. Normalizing by mass of wood burned yields regional composite emission factors which include both fireplace and wood stove combustion. Emission factors ranged from 2.8 g kg^{-1} wood burned in the Pacific Northwest to 4.7 g kg^{-1} in EPA Region 7 encompassing Iowa, Kansas, Missouri, and Nebraska. The regions in the central United States tended to yield higher emission rates per unit wood burned than the regions located on the east or west coast. This trend is due to a greater prevalence of fireplaces which produce higher fine-particle emission rates than wood stoves.

[15] On a per unit land area basis, Table 1 shows that fine-particle emissions from residential wood combustion are most concentrated in the Northeast where population density is generally higher and cooler weather increases the need for home heating. In western states that have lower population densities and/or warmer climates, the emissions density per unit land area is considerably less. On a per capita basis, fine-particle residential wood combustion emissions are highest in New England and trend lower toward the west. The notable exception is EPA Region 7, which is explained by high emission rates from the types of wood burned in those states as well as the aforementioned prevalence of fireplaces. Table 1 also shows that the majority of fine-particulate mass emitted from residential wood combustion consists of organic carbon, a result that is consistent with previous work [*Fine et al.*, 2001, 2002; *Schauer et al.*, 2001; P. M. Fine et al., submitted manuscript, 2001a, 2001b, 2001c]. A detailed listing of the organic species which make up the organic carbon mass are given in these previous papers along with mass balances showing the major classes of organic compounds emitted as a fraction of total organic compound mass.

[16] The cellulose pyrolysis product, levoglucosan, has been proposed previously as a general organic tracer for wood smoke particles [*Fraser and Lakshmanan*, 2000; *Simoneit et al.*, 1999] and has been used successfully in chemical mass balance calculations to aid in apportioning ambient fine-particle mass to wood combustion [*Schauer and Cass*, 2000]. This compound is nonvolatile, existing predominantly in the particle phase as shown by source tests on fireplace combustion conducted by *Schauer et al.* [2001]. The presence of levoglucosan in the atmosphere, as well as its atmospheric stability with respect to acid-catalyzed hydrolysis in aqueous droplets, has been demonstrated by

Table 1. Results by EPA Region for Residential Wood Combustion (RWC) Emissions in 1995

U.S. EPA Region	States Included	Total Wood Burned for RWC, 10^3 metric tons	$PM_{2.5}$ Emissions From RWC, 10^3 metric tons	$PM_{2.5}$ Emission Factor for RWC, g kg^{-1} wood burned	$PM_{2.5}$ Emissions per Land Area, kg km^{-2}	$PM_{2.5}$ Emissions per Capita, kg $individual^{-1}$	$PM_{2.5}$ Organic Carbon, 10^3 metric tons	Levoglucosan Emissions, 10^3 metric tons
1	CT, ME, MA, NH, RI, VT[a]	2900	10	3.7	65	0.79	7.6	1.0
2	NJ, NY[b]	4300	15	3.4	100	0.57	11	1.5
3	DE, MD, PA, VA, WV, DC[c]	3800	15	3.9	47	0.55	11	1.5
4	AL, FL, GA, KY, MS, NC, SC, TN[d]	6400	25	3.9	26	0.51	18	2.3
5	IL, IN, MI, MN, OH, WI[e]	4900	22	4.4	26	0.45	17	2.4
6	AR, LA, NM, OK, TX[f]	2300	9.8	4.2	6.9	0.32	7.7	0.88
7	IA, KS, MO, NE[g]	1700	8.3	4.7	11	0.67	6.2	0.93
8	CO, MT, ND, SD, UT, WY[h]	1000	4.1	3.9	2.7	0.48	3.1	0.47
9	AZ, NV, CA[i]	4400	15	3.5	16	0.41	12	1.8
10	ID, WA, OR[j]	1900	5.3	2.8	8.4	0.55	4.4	0.85

[a] Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.
[b] New Jersey and New York.
[c] Delaware, Maryland, Pennsylvania, Virginia, West Virginia, and District of Columbia.
[d] Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee.
[e] Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin.
[f] Arkansas, Louisiana, New Mexico, Oklahoma, and Texas.
[g] Iowa, Kansas, Missouri, and Nebraska.
[h] Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming.
[i] Arizona, Nevada, and California.
[j] Idaho, Washington, and Oregon.

Fraser and Lakshmanan [2000]. The very high emission rates of levoglucosan are shown in Table 1, with between 9% and 16% of the total fine-particle mass emitted from residential wood combustion consisting of this single compound. The presence of levoglucosan in ambient samples, its apparent atmospheric stability, and its high emission rate make it an ideal marker for wood smoke in general. Figure 2 displays regional levoglucosan emissions in a manner useful as input to chemical mass balance receptor modeling calculations; levoglucosan emissions are normalized to total particulate organic carbon mass. It is evident that a single levoglucosan emission factor might not be applicable to residential wood combustion throughout the United States. Woods burned in the Pacific Northwest emit greater relative quantities of levoglucosan than the other regions, while considerably lower relative amounts are emitted in the region that includes Texas. If one is to use levoglucosan as a wood smoke tracer, regional differences in wood and appliance types should be considered when developing a source profile for chemical mass balance modeling purposes.

[17] Regional variations like those observed for levoglucosan emissions from residential wood combustion are also seen in the emissions of other potential organic wood smoke tracers. Two lignin pyrolysis products, coniferyl aldehyde and sinapyl aldehyde, are known components of wood smoke [*Fine et al.*, 2001, 2002; P. M. Fine et al., submitted manuscript, 2001a, 2001b, 2001c] which also exist primarily in the particle phase of wood smoke emissions [*Schauer and Cass*, 2000]. The substituted guaiacol compound, coniferyl aldehyde, is found in the smoke from the combustion of both hardwoods and softwoods. Sinapyl aldehyde, a substituted syringol compound, is only found in the emissions from hardwood combustion. Regional differences in hardwood/softwood availability thus translate into regional differences in the emissions profiles of these compounds, as shown in Figure 3. In the western United States, where hardwoods are less available than in other regions east of the Rocky Mountains, emissions of sinapyl aldehyde as a fraction of fine-particle organic carbon are relatively low, while coniferyl aldehyde is emitted at similar levels relative to fine-particle organic carbon within all of the regions. These two compounds have also been measured at relatively high concentrations in ambient samples from the San Joaquin Valley of California [*Schauer and Cass*, 2000]. The chemical mass balance model accompanying that study was able to distinguish between hardwood and softwood smoke in the atmosphere by using substituted syringols as tracers for hardwood smoke.

[18] Another potential wood smoke marker emitted primarily from hardwood combustion is the lignin pyrolysis product, propionyl syringol. This substituted syringol compound was measured in ambient samples and used successfully as a hardwood combustion marker in the San Joaquin Valley study [*Schauer and Cass*, 2000]. It is a known component of wood smoke [*Fine et al.*, 2001, 2002; P. M. Fine et al., submitted manuscript, 2001a, 2001b, 2001c] which has been shown to exist primarily in the particle phase [*Schauer et al.*, 2001]. There are no data available concerning its atmospheric stability. Figure 4 shows the

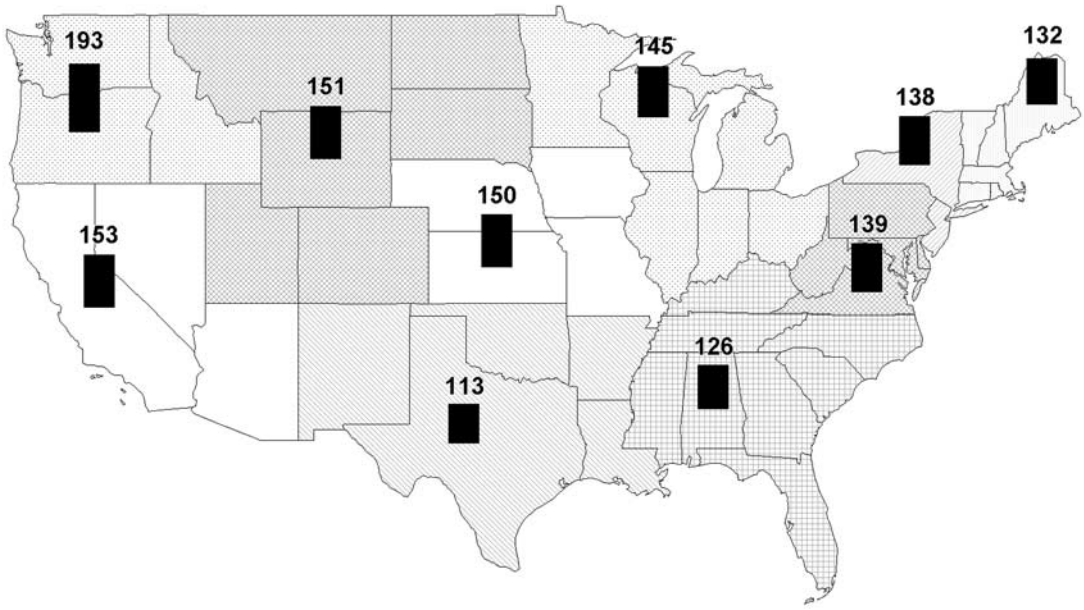

Figure 2. Levoglucosan emissions from residential wood combustion in milligrams per gram organic carbon.

regional variation in the emissions of this compound which is driven by the same hardwood and softwood availability patterns observed above for sinapyl aldehyde.

[19] Also shown in Figure 4 are the regional emission rates for β-sitosterol, another potential wood smoke marker. A phytosteroid present in plant lipids [*Simoneit*, 1989], β-sitosterol volatilizes during incomplete combustion and subsequently recondenses into the particle phase. Its high molecular weight assures its complete partitioning into the particle phase. The amount of β-sitosterol has been measured in ambient particle samples [*Simoneit et al.*, 1999], but it has not yet been used in chemical mass balance calculations. The emission rates of β-sitosterol can vary widely depending on the wood species being burned [*Fine et al.*, 2001, 2002; P. M. Fine et al., submitted manuscript, 2001a, 2001b, 2001c]. However, using our source test data combined with wood use data, it is possible to arrive at regionally averaged emission rate estimates for this compound.

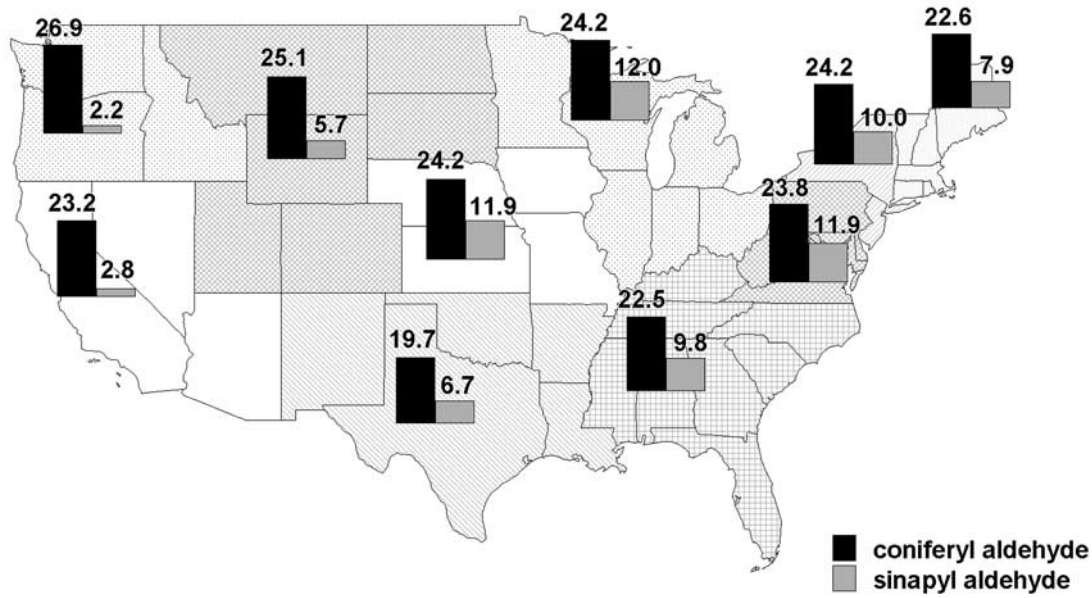

Figure 3. Coniferyl aldehyde and sinapyl aldehyde emissions from residential wood combustion in milligrams per gram organic carbon.

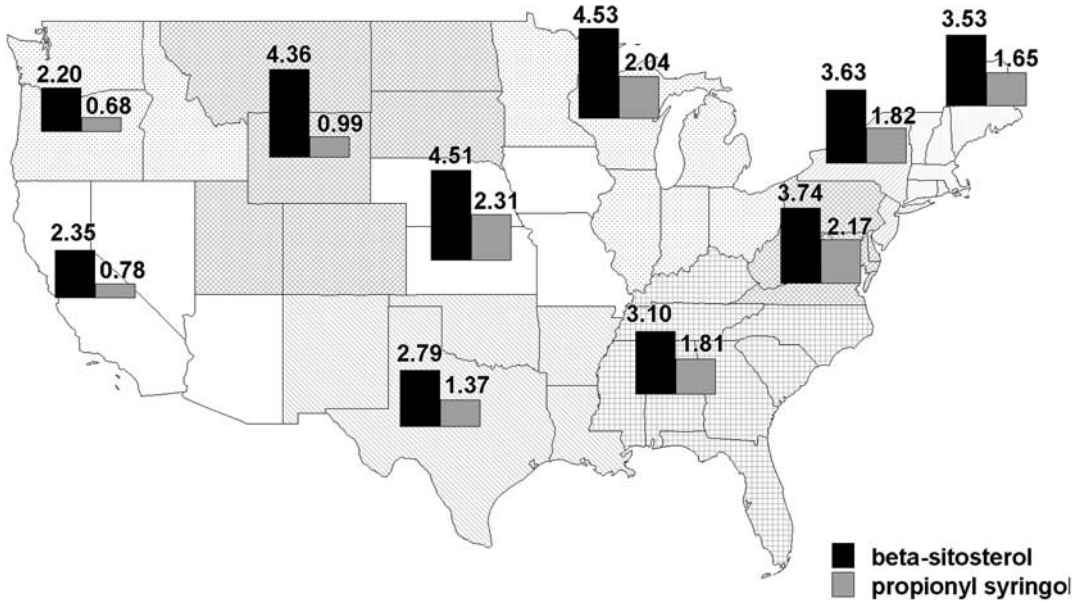

Figure 4. Emissions of β-sitosterol and propionyl syringol from residential wood combustion in milligrams per gram organic carbon.

Generally, more β-sitosterol is emitted from hardwood combustion than from softwood combustion. The lower β-sitosterol emission rates in the western United States seen in Figure 4 are likely due to the lesser availability of hardwoods in the West, as mentioned before.

[20] The final class of organic wood smoke markers examined in this study consists of resin acids. These resin acids are derived from conifer wood resins or their thermal alteration products [*Simoneit et al.*, 1993]. Therefore they are emitted almost exclusively from softwood combustion, as has been demonstrated previously [*Fine et al.*, 2001, 2002; P. M. Fine et al., submitted manuscript, 2001a, 2001b, 2001c]. Resin acids have been found only in the particle phase of wood smoke emissions [*Schauer et al.*, 2001]. Figure 5 shows the regional variation in the relative emission rates of these five resin acids. Pimaric acid, isopimaric

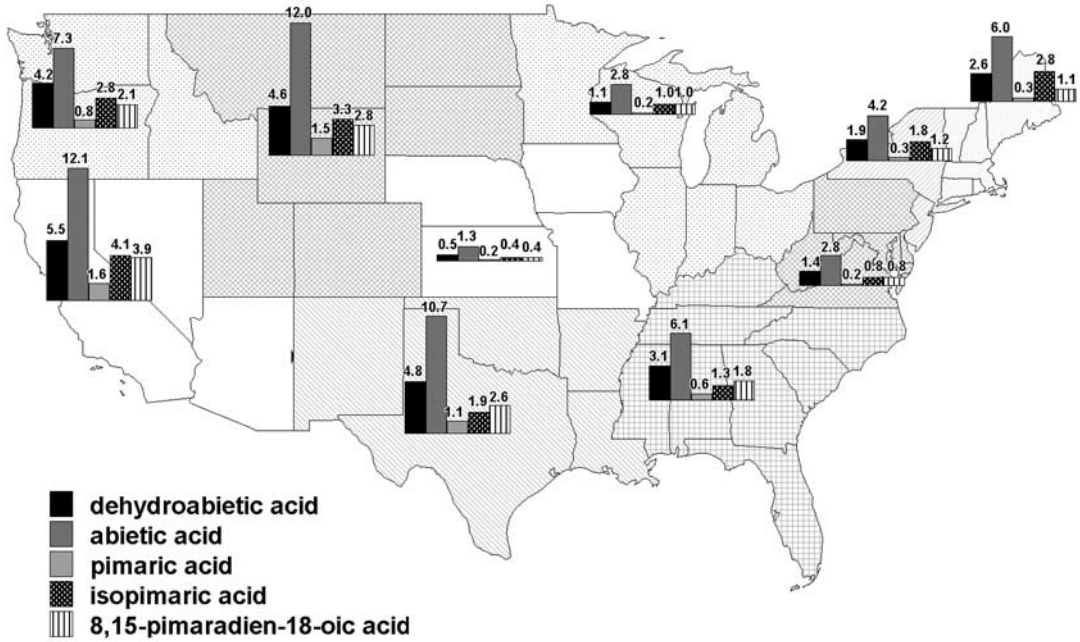

Figure 5. Resin acid emissions from residential wood combustion in milligrams per gram organic carbon.

acid, and 8,15-pimaradien-18-oic acid have all been measured in ambient samples and have been used previously in chemical mass balance calculations [*Schauer and Cass*, 2000]. Abietic acid and dehydroabietic acid have been included in Figure 5 owing to their generally higher emission rates. The higher level of softwood combustion in the western states leads to significantly higher emission rates of resin acids in the West when compared to the eastern United States. Region 7 (Iowa, Kansas, Missouri, and Nebraska) shows very low resin acid emissions presumably owing to the low availability of softwoods in that area.

[21] Figure 5 shows that the relative amounts of individual resin acids emitted from residential wood combustion can vary regionally. For instance, more isopimaric acid is emitted than 8,15-pimaradien-18-oic acid in the western and northeastern regions. This trend is reversed in the other regions of the United States and is a result of different emission rates of resin acids from the different softwood species available in these regions. When used together with the substituted syringol markers discussed above, the inclusion of resin acids in chemical mass balance models can aid in distinguishing between hardwood and softwood smoke. Since differences among the emission characteristics from different softwood species can lead to different emission profiles in different regions, it is important that receptor modeling calculations for wood smoke be based on the wood species and appliance type distributions that exist upwind of the particular receptor site of interest.

4. Conclusions

[22] Chemical mass balance receptor models that use organic compounds as tracers for specific emissions source types are an important tool in determining the source contributions to ambient fine-particle samples. The success of models of this type relies on having accurate source chemical composition profiles as input. Residential wood combustion is one of the largest sources of fine-particle emissions to the atmosphere in North America. Since wood-burning practices and activities can vary geographically, residential wood combustion chemical composition profiles also differ by region. The approach outlined in this paper, when combined with detailed emissions data from source testing, provides a method for calculating regionally averaged residential wood combustion source signatures. Comparison of regionally averaged compound-specific emissions rates shows that the relative amount of the general wood smoke tracer levoglucosan emitted per gram organic carbon in wood smoke varies by less than a factor of 2 across all regions of the United States. Within that factor of 2, a quick estimate of wood smoke particle concentrations in the U.S. atmosphere can be obtained in situations where one is fairly sure that residential wood combustion is the source of the wood smoke. Other compounds that are directly linked to hardwood combustion vary over a wider range which reflects regional differences in the prevalence of hardwoods versus softwoods. The relative emission rate of sinapyl aldehyde, which is derived largely from hardwoods, varies by more than a factor of 5 among the geographic regions studied. By quantifying the similarities and differences between the wood smokes generated in different regions, source chemical composition profiles can be developed that will help to quantify the amount of wood smoke in the atmosphere and that might even act as a signature for the geographic origin of a particular air mass.

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